Appendix C-3
Design Options for Watercraft Electrical Systems to Reduce Electrical Hazards and Improve Operability

**IMPORTANT USER NOTE: This document was created in 2014 by the DOD Electrical Safety Working Group (ESWG) and is based on Codes and Standards in force in 2014. To use this document properly, the user must refer to the code in force at the date of use.*

Design of safe systems and the use of equipment systems with fewer potential hazards is the most effective way to enhance personnel safety, reduce mishaps and enhance system and equipment reliability and operability. Electrical hazards are anticipated and controlled before the equipment becomes operational so that hazards that could impact electrical systems and workers are removed or minimized. Electrical safety becomes an integral part of designs integral to functionality, rather than an after-thought to meet on-going regulations, or as a mitigation measure after a serious mishap.

SAFE DESIGN REQUIREMENTS

The European Union has established legal requirements for inherently safe design. Several EN and ISO standards address electrical safety in design. ISO 13849-1:2006, "Safety of Machinery – Safety Related Parts Of Control Systems" provides instructions to designers to make machines safe. These instructions include recommendations for system design, integration and validation, as well as special requirements for safety-related parts that have programmable electronic systems. EN 62061: 2005, "Safety of Machinery – Functional Safety Of Safety Related Electrical, Electronic And Programmable Electronic Control Systems" is a machinery safety-related standard within the International Electrotechnical Commission (IEC) 61508 (2007), "Functional Safety" framework. IEC/EN 62061 is the standard for designing electrical safety systems. It includes recommendations for the design, integration and validation of safety-related electrical, electronic and programmable electronic control systems for machinery.

In the United States, the legal requirements for a safe land-based workplaces are established in 29CFR 1910 for general industry 1926 for construction and 1915 for maritime. IEEE Standard 45-2002, or more recent edition, "Recommended Practice for Electrical Installations on Ships" is incorporated by reference into 46 CFR 110.10-1 (Coast Guard) and provides electrically safe design recommendations for AC power systems, DC power systems, emergency power systems, shore power, power quality and harmonics, electric propulsion and maneuvering systems, motors and drives, thrusters, and steering systems. The standard provides a consensus of recommended practices for systems engineering in marine electrical engineering as applied specifically to ships, shipboard systems and equipment. It provides recommendations for systems engineering,

design and integration of electric systems from concept design through the establishment of the design baseline. IEEE P45.1, "Recommended Practice for Electrical Installations on Shipboard – Design" is an extension of the baseline technology and methods covered in IEEE Standard 45 and provides a consensus of recommended practices for design in marine electrical engineering for shipboard systems, and equipment.

DESIGN AND EQUIPMENT SELECTION OPTIONS WHICH CAN ENHANCE OPERATION AND SAFETY

System design and equipment selection, as well as proper maintenance, are integral to reliable system function. Several options appropriate for shipboard use are described in the following discussion.

High Resistance Grounding System

High Resistance Grounding (HRG) systems limit the fault current when one phase of the system shorts or arcs to ground. HRG reduces arcing current and arc-flash hazards associated with phase-to-ground arcing; prevents operation of overcurrent devices until the fault can be located; requires a ground fault detection system to provide notification that a ground fault condition has occurred; and may be utilized on low voltage systems or medium voltage systems up to 5kV.

Covered or Isolated Bus

The energy associated with a single phase is less than the energy associated with a multi-phase fault. A covered or isolated bus prevents a single phase fault from becoming a multi-phase fault. In addition, the covered or isolated bus helps prevent the single-phase fault from occurring. Covering or isolation is not designed to protect personnel from the energized bus.

Touch-Proof Equipment

Touch-proof equipment prevents workers from contacting energized terminals directly or with equipment they are using. The touch- proof equipment reduces the likelihood that a worker will come in contact with energized circuits or conductors. This protection prevents an arc flash due to accidental phase-to-ground and/or phase-to-phase contact. ANSI/IEC Standard 60529-2004, Degrees of Protection Provided by Enclosures (IP Code), is a consensus standard that describes a system for classifying protection provided by enclosures of electrical equipment for two conditions: 1) the protection of workers against access to hazardous parts (i.e., touch-proof), and protection of equipment against the ingress of solid foreign objects; and 2) the ingress of water. The Standard can be viewed at: https://www.nema.org/Standards/ComplimentaryDocuments/ANSI-IEC-60529.pdf. The degree of protection is designated by an IP Code. One method to ensure worker protection is to specify and use enclosures with IP ratings for the intended environment.

Arc Resistance Enclosures

Arc resistant enclosures (e.g., arc resistant switchgear) help contain the arc and the arc byproducts and redirect the arc energy away from the worker.

Arc Suppression Systems

Arc suppression products actively look for the occurrence of an arc fault. When detected suppression circuitry extinguishes the arc.

Fully Withdrawable Motor Control Centers

The fully withdrawable motor control center design ensures physical access to the inside of the unit can only be gained by removing the unit from the power bus. This reduces the potential for inadvertent contact with energized parts.

Ground-Fault Circuit Interrupters

Ground-Fault Circuit Interrupters (GFCIs) protect devices and persons from shock by continuously monitoring the current and tripping when current leakage is detected.

Viewports To Allow Thermographic & Ultrasonic Inspection Without Removing Covers

Inspection viewports are devices that enable infrared and ultrasonic inspections of switchgear and other power distribution equipment without opening doors or removing covers that would expose workers to lethal energy. Thermographic monitoring is used to monitor temperature rises so that preventive measures can be taken.

Luminaires Selection

The *National Electrical Code (2014)* Article 410 covers Luminaire requirements. Fluorescent luminaires that utilize double-ended lamps and contain ballast(s) that can be serviced in place shall have a disconnecting means either internal or external to each luminaire. A disconnecting means enables personnel to de-energize a luminaire easily without disabling the power at its source. Quick disconnects reduce the hazard of contacting energized circuits. Using these quick disconnects prevents the possibility of electrocution during maintenance, repairs and replacement.

Electrical Shore Connectivity

Connecting to an improperly wired shore-power system can create potentially harmful conditions for personnel as well as causing damaging galvanic currents. In 120-volt single-phase power distribution, one of the conductors is designated the "hot" wire (the black wire in North America) and the other, the neutral (the white wire). Keeping track of which wire is the neutral is necessary in order to prevent potentially dangerous wiring. In a properly wired AC system, there should be no significant voltage difference between the neutral wire and the safety ground wire.

An incorrect connection may be detected by sensing a current flow between the neutral wire from the shore-power system and the electrical system's safety ground. Visible indicators can prevent reverse polarity conditions. Reverse polarity indicating devices and reverse polarity trip coils provide continuous visible and/or audible signals or service trip, and respond to the reversal of the ungrounded and the grounded conductors.

Arc Resistant Switchgear

Arc faults within switchgear can be caused by a number of factors, such as loss of insulating properties resulting from elevated or extreme temperatures. Also, the presence of dust, contamination, or moisture on insulating surfaces leads to tracking across insulating surfaces, providing a path for conduction between two different potentials. Arc resistant switchgear directs the energy released during an arc fault in ways that minimize the potential for injury to personnel and damage to equipment. The most commonly referenced standard for arc-resistance is ANSI/IEEE C37.20.7-2007, "IEEE guide for testing metal-enclosed switchgear rated up to 38 kV for internal arcing faults". The types defined in ANSI/IEEE C37.20.7 are Type 1: Arc-resistant functionality at the front of the equipment only, and Type 2: Arc-resistant functionality at the front, rear and sides of the equipment.

Arc Fault Circuit Interrupters

Arc fault circuit interrupters rapidly detect potentially dangerous arcs and disconnect power in the circuit before a fire can start.

Remote Racking

Remote racking devices permit the insertion and removal of electrical devices while the operator is outside the flash protection boundary. Electrically operated devices, such as motor control and switchgear, can be opened and closed from a remote location which removes the operator from the arc flash protection boundary. A remote switch operator control unit and appropriate switch actuator allow servicing of equipment to operate, trip and close circuit breakers from a safe distance outside the arc flash boundary.

Remote Switching

Remote switching allows the worker to be removed from the arc flash boundary while performing required work. Different remote switches are available for different switching operations such as remote operation of a power circuit breaker, remote operation of a control switch, or remote racking of a circuit breaker. Electrical workers can rack a breaker for example, for electrical panels from a safe distance without the need to be in sight of the breaker.

Covers, Doors and Barriers

Mechanical integrity of covers, doors, and barriers affects the electrical safety risk analysis. The safety of equipment is determined in part by the mechanical strength and durability, including parts designed to enclose and protect equipment; the adequacy of the protection provided; and by other factors that contribute to the practical safeguarding of persons using, or likely to come in contact with the equipment.

NEW TECHNOLOGIES

As new technologies prove reliable, equipment is being developed for integration into electrical systems.

Microprocessor Based "Intelligent Controllers", or "Smart" Motor Control Centers

Smart motor control centers and substations incorporate self-diagnostic capability and data communications enable remote trouble-shooting, adjustments, and failure recovery, reducing the need for a worker to be exposed to hazardous energy.

Fast overcurrent Detection and Arc Flash Detection

The best and most direct way to reduce arc flash hazards is to reduce fault-clearing times including using fast overcurrent and arc flash detection technologies. Arc-flash light detection to reduce the risk of an arc flash in low- and medium-voltage panels and switchgear equipment is a growth area of electrical safety research. Fast overcurrent detection and arc-flash detection sensors provide a way to reduce arc-flash incidents. Arc flash detection methods may include light or current detection. These systems use light detection and current sensing to detect an arc and initiate high speed clearing of the circuit. By quickly detecting a ground fault and initiating the response, ground fault relays improve electrical safety and minimize damage to equipment due to electrical faults.

Protective Relays Reducing Incident Energies

Protective relays are an effective method for reducing the energy of an arc flash. Combining arc-flash detection and high-speed overcurrent with a protective relay provides fast tripping and security, using both instantaneous overcurrent and light from the arc flash. "When conductors with good insulation are exposed to fault initiators such as moisture, dust, chemicals, persistent overloading, vibration or just normal deterioration, the insulation will start to slowly deteriorate. Such small changes will not be immediately obvious until the damage is severe enough to cause an electrical fault. Relays can detect that a problem is developing by identifying slight deviations in current, voltage, resistance, or temperature. Due to the small magnitude in change,

only a sophisticated device such as a sensitive protection relay or a monitor can detect these conditions and indicate that a problem may be developing, before further damage has occurred."[1]

Zone selective Interlocking Systems

Fault-clearing times are reduced at locations where solid-state trip units are using zone interlocking features. This feature adds communication between the main, tie, and feeder breakers. If a fault occurs the overcurrent protective device will then trip at a very low time delay which can immediately put an end to the arc flash event.

Advanced Electric Power Systems

Research is ongoing to advance the field of power systems technology. This research can lead to novel and new methods for protecting equipment and electrical systems from adverse outcomes.

ENHANCING SAFE OPERATION OF EXISTING WATERCRAFT ELECTRICAL POWER SYSTEMS

While Safe Design is the best solution to reduce risk, there is a well-established process to identify and reduce hazards in existing systems. A power system study is an extremely important tool to both enhance operation and reduce risk by reducing energy disruptions while ensuring the safe operation, integrity and operability of electrical systems. The study, which can be performed both before electrical systems become operational, or at any time thereafter, includes:

- Short circuit studies
- Coordination studies
  - Design and application of proper coordination of relay and circuit breaker settings
  - Overcurrent clearing time engineering evaluation
  - Direction and amount of power flowing from available source to every load
- Shock risk assessment
- Arc flash risk assessment
  - Incident energy exposure at working distance
  - Arc flash boundary

A Short Circuit Study identifies the maximum available fault current at all locations in the power system. The maximum available fault current is then compared with the ratings of the individual power system components to determine if the equipment is adequately rated to safely withstand

[1] Littlefuse, "How do Protection Relays Work?" Retrieved from: http://www.littelfuse.com/products/relays-controls-and-systems/protection-relays/protection-relay-pages/how-do-protection-relays-work.aspx

or interrupt the fault current. The results of the short circuit study are also used in both the coordination study and the arc-flash study.

A Coordination Study is identifies impacts of short circuits and equipment failures. It determines these effects on operations which can improve power system reliability. A protective device coordination study analyzes the impacts of short circuits and equipment failures within a facility and determines the effects on system operation. An overcurrent clearing time protective device coordination study is used to provide a basis for selecting and setting protective devices to isolate and clear faulting circuits as quickly and safely as possible, while all other protective devices remain closed, continuing power to the entire un-faulted part of the system. The study should be performed prior to initial operation in order to select, or to verify the selection of, power fuse ratings, protective-relay characteristics and settings, ratios, and characteristics of associated voltage and current transformers and low-voltage breaker trip characteristics and settings. Proper coordination of relay and circuit breakers settings is the easiest and simplest method to reduce arc flash hazards and provide the best protection to workers.

A Shock Risk Assessment identifies the shock protection boundaries and associated protective equipment requirements. These boundaries are applicable where personnel approach energized electrical components or conductors and personnel are directly exposed to contacting these energized electrical conductors and circuit parts. The protection boundaries are dependent on nominal system voltages and apply both to direct current (DC) and alternating current (AC).

An Arc Flash Risk Assessment identifies incident energy at a prescribed working distance. It is used to determine the arc flash boundary as well as appropriate arc-rated personal protective equipment required in the arc flash boundary. This risk assessment determines appropriate arc-rated protective clothing and other insulated protective equipment (such as insulated blankets) required within the arc flash boundary. The importance of arc flash risk assessment is to evaluate electrical arc hazards which provide the necessary information to a qualified electrical worker for safe work practices. Safe work practices can be followed if the worker has to work on electrical equipment not in an electrically safe working condition. The available short circuit current and the total clearing time at each designated piece of electrical equipment is needed to perform an arc flash hazard analysis. IEEE 1584-2002, “Guide for Performing Arc-Flash Hazard Calculations” provides suggested calculation methods. The arc flash risk assessment should be repeated if there are changes that occur that affect the arc flash, such as changes in the available short circuit or in the overcurrent protective devices.

CONCLUSION

Reliable design and technologies are available to protect electrical systems. “Designing out” hazardous exposures to electrical energy reduce risks from fires, equipment failure and damage, and personnel injuries or death.